Radiation-Induced transient effects in near Infrared focal plane arrays

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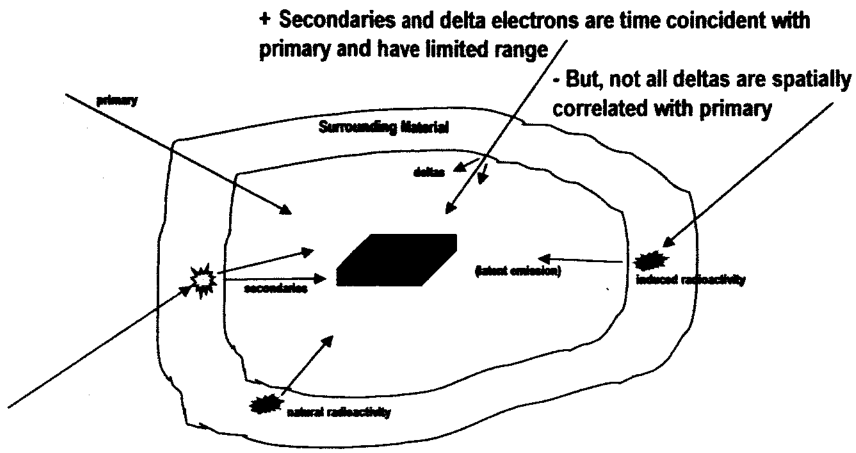
Agenda

- Background/Problem
- Testing Goals and Strategy
- Test Data and Discussion
- Conclusions

Ionizing Particle Impacts to FPA



Even Small Transients can be Problematic for NIRCAM

- Read noise requirement is very low
- Essentially every primary particle and every secondary particle causes a transient that exceeds noise level
- Cosmic ray rejection algorithms can tolerate limited number of hits within integration time
- Problem is exacerbated by:
  - Crosstalk (charge spreading to neighboring pixels)
  - Multi-pixel hits (e.g., hit detector and ROIC in different pixels)
  - Secondary particles that are not spatially correlated to primary

TESTING GOALS, STRATEGY AND APPROACH

Transient Test Objectives

- Characterize proton single events as function of energy and angle of incidence
  - Pulse height distributions provide information for model calibration
- Measure charge spread (crosstalk) to adjacent pixels
  - Key parameter for determining number of disturbed pixels
- Assess transient recovery time
  - Look for long transients (collection of ionization-induced charge or persistence of radiation-induced dark current)
  - Characterize reset after hit

Devices Tested

- Test ROIC without detectors and test SCA (detectors plus ROIC) to separate effects
- Test 1024x1024 versions (H1RG and SB291)
  - Subset of identical circuitry on 2048x2048 versions

Device	Test Date	Energies	Angles	Comments
H1RG ROIC	5-16-02	30, 63	0	Single event and dose
H1RG SCA	10-16-02	30, 63	0, 45, 67	Single event, dose and secondaries from Al
SB291 ROIC	2-11-03	30, 63	0, 45, 67	Single event and dose
SB291 SCA	3-31-03	30, 63	0, 45, 67	Single event, dose and secondaries from Al

Transient Test Strategy

- Use 30 and 63 MeV protons
- Use 0, 45 and 67 degree incidence
- Use low flux for single events
  - 1e3 to 1e5 p/cm^2-s range
- Use quilt-mode readout of 20x100 subarray
- Multiple samples at 10 Hz (100 ms) using variable integration time Fowler-mode integrations (reset, read$_1$, read$_2$, ... read$_i$, reset)

Mode	#Reads	Time Between Reset (ms)
F1	2	200
F2	4	400
F5	10	1000
F10	20	2000

  - Designed to capture transient recovery

20*x100 Subarray Used for Single Event Testing

*Effectively 20x96 since includes 2 reference columns on each side

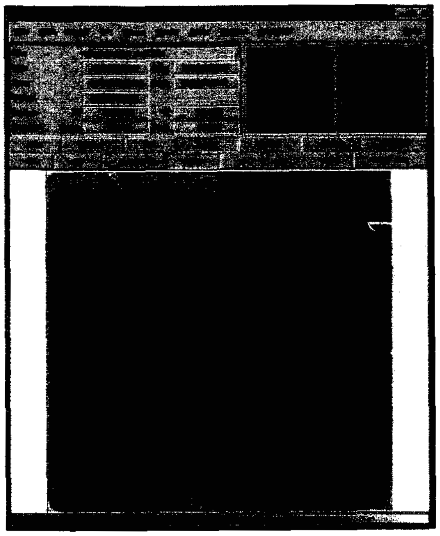


Figure 3. Example of a full frame pedestal (reset-read digitized) 1024x1024 image. Pixel (0,0) is located in the lower left hand corner. The green box represents the location of the subarray used in for single-event testing.

TEST DATA AND DISCUSION

Typical Proton-Induced Pulses

H1RG SCA
30 MeV

0 Degrees

5331	170	4	19	-17	2	8
100	-74	-55	52	-32	-15	92
20	20	-67	388	430	740	8121
-4	-4	507	28057	7582	14056	4931
-89	38	67	786	16245	1791	129
32	-136	87	2489	14295	24719	847
12	-48	564	7287	673	321	47

-79	25	35	-7	-34	0	23
-17	-40	-5	37	13	-27	0
-12	71	12	291	233	-100	28
-27	22	253	17941	16257	555	58
-10	-19	72	5522	5580	9946	3109
32	22	-53	68	245	6379	2290
-40	-123	14	-13	4	-190	-450

379	5	61	13	-107	-43	67
470	252	194	353	23	194	328
43	216	11309	26399	1941	14928	5209
14	-52	467	36916	2939	15373	5436
43	-15	12	468	-20	122	433
4178	1455	223	13403	2251	382	22117
12017	3043	82	88	-48	8	4268

67 Degrees

-34	-23	70	47	-64	-3	-23
23	44	-40	-20	7	17	-17
9	-1	382	15883	12699	449	29
17	-20	368	16389	14280	488	27
-27	26	36	249	215	49	-1
-3	0	23	0	-18	22	281
7	-10	37	17	-40	10	50

-64	-13	34	-34	0	44	-30
20	52	-20	-3	47	-37	-40
33	-8	197	415	72	-68	3
19	250	15232	28544	870	48	8
-4	58	4270	4773	284	19	50
-3	-30	40	57	10	-111	-621
7	44	-17	-17	-20	23	-23

-30	-3	64	-20	-13	3	-17
-64	-7	34	20	-23	-20	40
-44	-15	52	531	52	2	-13
7	42	2452	38147	4144	139	-25
-7	29	1505	17378	2880	115	31
10	-3	14	272	58	11	-40
13	37	-20	-37	20	17	-7

Typical Proton-Induced Pulses

SB291 SCA
30 MeV

0 Degrees

-2	-2	6	-2	12	-2	-12
18	-27	6	-18	2	-2	10
12	2	2	-4	2	2	-16
20	-9	-16	413	344	-12	-5
0	0	0	145	86	8	4
-18	23	6	113	94	14	-8
-43	105	16	6652	826	-6	-17

-1	-4	-4	-6	8	-8	12
-1	14	0	-10	0	18	2
-1	2	-18	4	12	-14	12
-1	191	13486	16126	64	-18	123
-2	18	661	230	-1	-1	0
-1	-10	-4	-4	10	46	2
-1	14	133	2322	14	-8	-10

-10	-6	16	29	-18	-23	2
4	-22	23	-10	16	25	-41
-12	-13	507	732	32	-10	-10
4	11	4826	7094	39	-16	8
2	-4	-10	2	-6	-20	14
6	20	-23	-10	6	-2	-6
-8	6	4	-6	6	-8	-16

67 Degrees

20	-4	2	-27	10	23	-4
-20	0	4	2	18	22	-43
-10	4	2	12	-8	-6	4
1670	1690	11876	15894	77	15	135
2258	2620	1388	3275	30	-29	6
43	-37	4	-2	16	25	-16
-14	-27	22	12	-10	-4	0

8	14	-22	2	-6	-2	16
388	397	22	173	769	54	701
34	51	-13	-28	13	61	1254
1048	2338	393	22447	7558	226	109
1118	1392	229	14716	11197	62	-27
-16	-3	28	-145	-11	12	2
10	35	-23	16	8	-6	-27

6	14	-23	25	12	-6	-6
16	-10	-4	6	4	13	-6
701	1013	46	2089	1981	-3	-22
1254	2515	247	22516	12965	90	-5
109	275	46	-40	8	-6	-4
-27	160	111	-15	13	2	2
2	2	0	6	-6	-4	-14

Hit Size Expected to Scale With Proton Energy and Angle of Incidence

- dE/dX { Linear Energy Transfer (LET) } is function of energy and material - lower at 63 MeV than 30 MeV
  - HgCdTe: 8.43 keV/um at 30 MeV; 4.91 keV/um at 63 MeV (x0.58)
  - InSb: 7.08 keV/um at 30 Mev; 4.09 Kev/um at 63 MeV (x0.58)
  - Si: 3.42 keV/um at 30 MeV; 1.92 keV/um at 63 MeV (x0.56)
- Charge generated ~ LET * Path
- Path through device scales as cos(angle)
  - x 1.41 at 45 degrees
  - x 2.56 at 67 degrees

PULSE HEIGHT DISTRIBUTIONS

- Difference between first read after reset and final read
- Data histogramed into 100 e bins
- Analysis for two types of distributions:
  - Distribution of pixel charges
    - Some charge from hit pixels counted in neighboring pixels
  - Distribution of total hit charges
    - Hits identified and all charge from neighboring pixels added

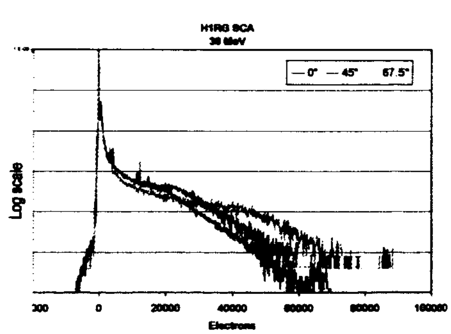
[redacted]

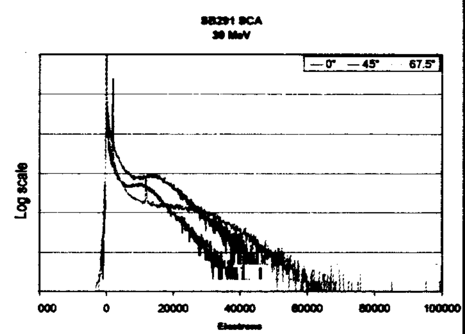
SCA Pulse Height Distribution

Distribution of pixel charges

SCA Comparison at Various Angles

30 MeV





- SCA pulses are larger than ROIC pulses
- Pulses scale with angle of incidence
- H1RG pulses are larger than SB291 pulses

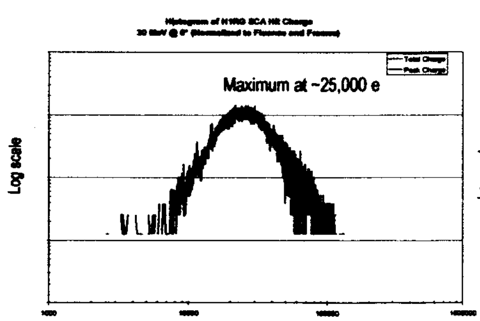
TOTAL CHARGE DISTRIBUTIONS

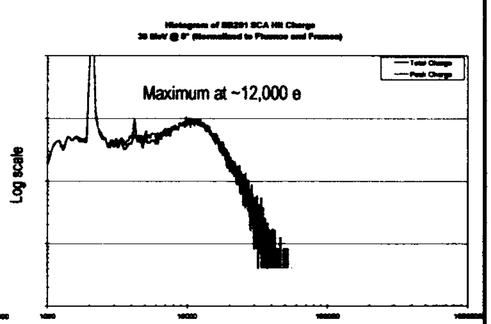
Total Charge : Charge to hit pixel and affected neighbors summed

Peak Charge: Charge to hit pixel only

SCA Total Charge Distributions

30 MeV, 0 Degrees





Total Charge Peaks Scale With Angle and Energy as Expected

Peak Locations

Energy	Angle	[redacted]	H1RG
30	0	[redacted]	23000
30	45	[redacted]	25000
30	67	[redacted]	48000
63	0	[redacted]	9000
63	45	[redacted]	13000
63	67	[redacted]	25000

Angle Scaling

Expected	[redacted]	H1RG
1.00	[redacted]	1.00
1.41	[redacted]	1.09
2.56	[redacted]	2.09
1.00	[redacted]	1.00
1.41	[redacted]	1.44
2.56	[redacted]	2.78

Energy Scaling

Expected	[redacted]	H1RG
1.00	[redacted]	1.00
1.00	[redacted]	1.00
1.00	[redacted]	1.00
0.58	[redacted]	0.39
0.58	[redacted]	0.52
0.58	[redacted]	0.52

H1RG SCA pulses are somewhat larger than SB291SCA pulses

Measured Proton Crosstalk in H1RG SCA

63 MeV, 0 Degrees, 1976 Hits

-0.01%	-0.04%	-0.01%	0.01%	0.00%	-0.01%	-0.02%
-0.03%	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	-0.03%
-0.03%	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	-0.02%
-0.02%	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	-0.01%
-0.02%	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	-0.01%
-0.02%	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	0.00%
0.01%	0.00%	0.00%	0.01%	0.01%	-0.01%	0.00%

30 MeV, 67 Degrees, 1281 Hits

-0.03%	-0.01%	0.00%	0.00%	-0.02%	-0.02%	-0.02%
-0.02%	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	-0.03%
-0.04%	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	-0.04%
-0.03%	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	-0.03%
-0.04%	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	-0.04%
-0.03%	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	-0.03%
-0.03%	-0.03%	-0.02%	-0.03%	-0.03%	-0.01%	-0.01%

63 MeV, 67 Degrees, 1872 Hits

0.02%	-0.03%	-0.02%	-0.07%	-0.02%	-0.03%	-0.05%
0.01%	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	0.00%
-0.06%	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	-0.07%
0.00%	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	-0.11%
-0.03%	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	-0.09%
0.01%	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	-0.08%
-0.04%	0.01%	0.01%	-0.05%	0.00%	0.00%	0.00%

- Hits randomly distributed across pixel but all at same angle
- Hits are stacked by registration to hit pixel, not to hit centroid
- In some cases, charge is still above noise even at 2 pixels out from hit pixel

Measured Proton Crosstalk in SB291 SCA

30 MeV, 0 Degrees, 3755 hits

0.00%	-0.03%	0.02%	0.15%	0.03%	-0.02%	-0.03%
-0.02%	[redacted]					-0.02%
-0.02%						-0.03%
-0.05%						-0.10%
-0.03%						-0.05%
0.00%						-0.02%
-0.02%	-0.04%	0.01%	0.17%	0.08%	-0.02%	-0.02%

63 MeV, 0 Degrees, 1385 Hits

-0.03%	-0.03%	-0.02%	0.06%	0.00%	-0.03%	-0.02%
-0.02%	[redacted]					-0.02%
-0.02%						-0.04%
-0.03%						-0.07%
-0.03%						-0.04%
-0.02%						-0.02%
-0.02%	-0.08%	-0.01%	0.09%	0.02%	-0.04%	-0.09%

63 MeV, 67 Degrees, 614 Hits

-0.06%	-0.03%	-0.04%	0.12%	-0.09%	-0.08%	-0.07%
-0.13%	[redacted]					-0.15%
-0.12%						-0.21%
0.94%						-0.09%
-0.03%						-0.22%
-0.07%						-0.16%
0.02%	0.06%	0.03%	0.20%	-0.07%	-0.21%	-0.10%

- Hits randomly distributed across pixel but all at same angle
- Hits are stacked by registration to hit pixel, not to hit centroid
- In some cases, charge is still above noise even at 2 pixels out from hit pixel

Observations

- Pulses generally scale with energy and with angle as expected
- Unipolar pulses in SB291 (same polarity as detector)
- Bipolar polarity pulses in H1RG ROIC
- Pulses are smaller in ROIC than SCA for both H1RG and SB291
- Pulses with same polarity as detector have comparable size for H1RG ROIC and SB291 ROIC
- Pulses are larger in H1RG SCA than SB291 SCA
- Crosstalk is larger in SB291 ROIC than H1RG
- Crosstalk is larger in H1RG SCA than SB291
- Hit pixel recovery <100 ms or upon reset

General Conclusions

- Whatever technology chosen, JWST will have to live with cosmic ray hits
- Overall transient responses are similar at SCA level
  - ROIC hits are larger for SB291 than H1RG
  - H1RG SCA hits are larger (apparently due to detector)
  - H1RG proton crosstalk is worse (probably related to smaller pitch)
- Note that smaller pixels would have lower hit probability in space environment but more crosstalk